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Daylight fluctuations effect on the functioning of different daylight-linked control systems

Laura Bellia*, Francesca Fragliasso, Gennaro Riccio

Department of Industrial Engineering, University of Naples "Federico II", Piazzale Tecchio 80, 80125 Naples, Italy

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ABSTRACT

One of the problems preventing daylight-linked controls spread is users' reluctance in accepting them. Continuous electric light oscillations, determined by control systems, can annoy users. This problem is particularly relevant for switching systems and it is strictly dependent on sky conditions: the more variable the weather is, the more frequent the oscillations are. To deepen these issues, irradiance and daylight illuminance measurements were performed in a mock-up office. Percentage daylight fluctuations (PDFs) were calculated. Then, starting from measured data, the functioning of different switching systems (differential switching, switching with switching linked time delay, switching with daylight linked time delay and solar reset switching) was simulated, in order to investigate daylight fluctuations effect on controls performances. Simulations were repeated on varying dead band and time delay, to verify the effectiveness of techniques in reducing daily switching actions. Results demonstrates that when sky is clear, PDFs are generally comprised in the ranges [-5%; 0% [and [0%; 5% [both outdoor and indoor; whereas, when weather changes from a sky condition to another, fluctuations can be higher than 50%. Despite the choice of the switching technique is not univocal and its effectiveness strictly depend on specific indoor daylight availability, differential switching associated with a switching linked time delay turns out to be the strategy more adaptable to different cases. Moreover, not always the increment of the dead band extent or time delay corresponds to a reduction of the daily amount of switching actions.

1. Introduction

Daylight-linked controls represent a very useful strategy to optimize daylighting and consequently achieve substantial energy savings [1–6]. However, the spread of these systems in common applications turns out to be rather limited [7], since there are a lot of factors affecting their functioning [8,9] and consequently their design is not an easy task.

Certainly, one of the most relevant problems is users' reluctance in accepting them [10,11]. Indeed, if on one hand timers and occupancy-based controls have the goal to switch on and off or dim lights depending on people presence/absence and they maintain steady light conditions when spaces are occupied; on the other hand, daylight-linked controls continuously manage lighting systems during the entire occupancy period of a space [12]. This means that their effect on people comfort is higher compared to the two other control strategies and that, consequently, users' opinion about their installation is a very pressing issue during design process.

The automated control is often seen by users as an imposition and a previous study [13] underlined that the possibility to personally control lights and the environment is in general considered by people a mean to improve their own wellbeing and that, independently from the characteristics of the control system, the idea of exercising control in itself does represent a fundamental issue. However, automated controls can be appreciated by users if they can partially override them manually, especially when an improper functioning of the automated control occurs, such as sudden and unexpected increases of light or insufficient electric light levels when night falls [14]. Given that, the actual challenge for professionals is to optimize the performance of the systems, minimizing the automated regulations annoying people and consequently reducing users' intervention, that is likely to determine a loss in expected energy savings.

From the above considerations, a question arises: what are the regulations annoying users? When electric light levels continuously change to adapt themselves to daylight variations, two factors influence occupant visual comfort: the time between two consecutive light adjustments and the fluctuation entity. Then the more frequent are light changes, the more users are bothered and the higher is the difference between two consecutive illuminance levels, the more the light

* Corresponding author.
E-mail addresses: laura.bellia@unina.it (L. Bellia), francesca.fragliasso@unina.it (F. Fragliasso), riccio.gennaro@yahoo.it (G. Riccio).

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Nomenclature

$E_{w,dl}(t)$	Daylight illuminance at the work plane as a function of the time [lx]
$\delta(t)$	Electric light output as a function of the time [%]
$S_{dl}(t)$	Daylight component of the photosensor signal as a function of the time [lx]
$S_{el}(t)$	Electric light component of the photosensor signal as a function of the time [lx]
$S_{tot}(t)$	$S_{dl}(t)+ S_{el}(t)$ [lx]
$S_{tot,on}$	Limit photosensor signal under which switching systems turned light on [lx]
$S_{tot,off}$	Limit photosensor signal above which switching systems turned light off [lx]
$S_{el,\delta=100\%}$	Electric light photosensor signal when luminaires are fully on [lx]
δ_{max}	Maximum electric light output in dimming systems [%]
$S_{el,\delta max}$	Electric light photosensor signal when $\delta(t) = \delta_{max}$ [lx]
δ_{min}	Minimum electric light output in dimming systems [%]
$S_{el,\delta min}$	Electric light photosensor signal when $\delta(t) = \delta_{min}$ [lx]
δ_{tc}	Electric light output at the calibration time in dimming systems [%]
$S_{el,\delta tc}$	Electric light photosensor signal when $\delta(t) = \delta_{tc}$ [lx]
$E_{w,dl,tc}$	Work plane daylight illuminance at the calibration time [lx]

regulation is annoying, especially if the fluctuation occurs at low light levels [15]. Frequent and intensive light variations determine eye fatigue and visual discomfort due to the continuous effort of the visual system in adapting to different lighting conditions. Kim and Kim [15] conducted annoyance tests on 36 subjects, under different fluctuating illuminance levels, controlled by a lighting system in a full-scale mock-up office. They found that visual annoyance depends on the task illuminance subjects were initially adapted to. So, they underlined that when automated controls are involved and the risk of frequent light fluctuations is present, the task illuminance should not be lower than 650 lx and maximum illuminance fluctuations should not exceed the limit value of 40%.

The problem of continuous light oscillations obviously depends on sky conditions and it is more relevant when the weather is not stationary but continuously varies during the day. Sudden outdoor daylight variations correspond, indeed, to sudden indoor variations, since differently from building thermal behaviour, no inertia is present for lighting. In a previous study [16] it is reported that, with partly cloudy skies, outdoor vertical illuminance fluctuations can be 23.8 times greater than those observed under clear sky conditions.

Electric light fluctuations due to daylight variability are especially problematic when switching systems are installed. These systems allow only two lighting settings (completely on and completely off). So, considering that the increases and the decreases of light are necessary brusque, in order to improve these systems performances, it is fundamental to reduce the frequency of switching actions. Different techniques to achieve this purpose can be adopted, such as the introduction of dead bands and time delays. Previous works [17,18] focused on the effectiveness of these design strategies and, specifically, analysed the relationship between the number of switching actions per day and the achievable energy savings. However, they did not deepen issues connected to fluctuations frequency.

Dimming systems continuously regulate emitted flux, so the fluctuations are generally softer than those caused by switching systems. However, they can be very frequent as well. For example, Kim and Kim [16] studied the effect of daylight variations on dimming systems and suggested partially shielding photosensors, in order to reduce the correlation between outdoor fluctuations and the photosensor signal variations.

Given these premises, the goal of the paper is on one hand to observe and to analyse short term daylight fluctuations in real weather conditions and, on the other hand, to investigate their effects on typical daylight-linked control systems functioning. For this purpose, illuminance measurements were performed with a 1 min time step in a sidelit office located in Naples and simultaneously outdoor irradiance and illuminance data were acquired to monitor weather conditions. The daylight percentage fluctuations from one minute to another were calculated and examined both for outdoor and indoor measurements results. Then, by means of a specifically developed calculation tool (an Excel worksheet with macros), starting from the collected measurements, the functioning of different switching daylight-linked controls (differential switching, switching with switching linked time delay, switching with daylight linked time delay and solar reset switching) was simulated and the effectiveness of techniques to reduce the risk of too frequent switching actions was investigated. The number of daily switching actions and the period between two consecutive switching actions were calculated during some typical days. Finally, a dimming system functioning was modelled as well, to evaluate the electric light oscillations it produced and to compare them with those determined by switching systems. For all the simulated control systems, daily energy consumptions were calculated and compared. The use of short time daylight illuminance measurements is fundamental to accurately investigate control systems functioning. Indeed, generally simulations are performed starting from hourly data contained in weather data file and short time variations in system functioning are neglected. This determines remarkable uncertainties in describing systems performances and in defining achievable benefits in terms of both energy savings and visual comfort improvement, making difficult to establish if and how much automated controls installations are really convenient.

2. Method

2.1. Case study description

The case study is a square private office. It is about 4 m · 4 m · 3 m and it is located at the seventh floor (the top one) of one of the buildings of the University of Naples "Federico II" (Latitude 40° 51′ 22 N, Longitude 14° 14′ 47 E). The office is sidelit by two balcony windows: the former faces South and is about 1.5 m large and 2.6 m high, the latter faces West and it is about 2.1 m large and 2.6 m high. Both balcony windows are equipped with roller blinds, moreover the west one is also protected by a 1.6 m wide overhang. The room is equipped with typical office furniture: An L-shaped desk and a cabinet. Fig. 1 reports measured plan and section of the considered office.

This office double orientation drove the choice of the room: due to this characteristic, lowering a roller blind in turn, it was possible to obtain data referred to two different configurations, characterized by the same geometric and optical characteristics, but different daylighting conditions: a south-oriented office (when the west roller blind is completely closed and the south one completely open) and a west-oriented one (when the west roller blind is completely open and the south one completely closed).